THE VERTEBRATE FAUNAS OF THE LOWER OLD RED SANDSTONE OF THE WELSH BORDERS

PTERASPIS LEATHENSIS White A DITTONIAN ZONE-FOSSIL

BY

ERROL IVOR WHITE

Pp. 49–89; Pl. 5; 27 Text-figures

BULLETIN OF
THE BRITISH MUSEUM (NATURAL HISTORY)
GEOLOGY Vol. 1 No. 3
LONDON: 1950

THE BULLETIN OF THE BRITISH MUSEUM (NATURAL HISTORY) *instituted in 1949, is to be issued in five series, corresponding to the five Departments of the Museum.*

Parts will appear at irregular intervals as they become ready. Volumes will contain about three or four hundred pages, and will not necessarily be completed within one calendar year.

These papers form part 3, vol. 1 of the Geological series.

PRINTED BY ORDER OF THE TRUSTEES OF
THE BRITISH MUSEUM

31st.

Issued January 1950 *Price Seven shillings and sixpence*

THE VERTEBRATE FAUNAS OF THE LOWER OLD RED SANDSTONE OF THE WELSH BORDERS[1]

By ERROL IVOR WHITE

SYNOPSIS

An account is given of the vertebrates, chiefly Ostracoderms, from the 'Passage Beds' and Old Red Sandstone of the classical area of the Welsh Borders, with details of the localities from which they have been obtained. It is shown that these fossils may be used for zoning the Downtonian and Dittonian rocks over a considerable area, and tentative efforts are made at correlation with other areas. Both the series mentioned are re-defined and the question of the Silurian–Old Red Sandstone boundary is discussed, with a full account of the controversy concerning it, and argument is put forward for fixing it at the Ludlow Bone-bed.

INTRODUCTION

THE immediate purpose of this communication is to demonstrate that in the Anglo-Welsh area the strata between the Ludlow rocks and the Carboniferous, especially those below the Brownstones, may be zoned, at least tentatively, on the basis of their vertebrate fossils. This is not, however, merely a question of a local succession but has a far wider significance, for in this region is the type-area of the Silurian System and the 'Passage Beds', and until some such sequence is proven, not only will correlation with Continental and other areas be unsatisfactory but the important question of the Silurian–Old Red boundary must remain in doubt. Emphasis is of necessity placed on the vertebrate fossils which in these generally barren rocks provide by far the commonest remains over much of the area and in all but the lowest members of the succession (cf. Straw, 1930).

Elles & Slater (1906) used invertebrate fossils for zoning their 'Highest Silurian' strata in the Ludlow district, but this work only affected the Temeside Series comprising not more that 170 ft. of rock in the area concerned. Jones (1929: 120A) added two vertebrate zones to cover the succeeding 'Red Downtonian', some 2,000 ft. of rocks, an upper zone of *Tolypaspis* and *Cyathaspis*, and a lower zone of *Auchenaspis* (*Thyestes*) and *Didymaspis*, but a glance at the distribution of fossils given in Text-fig. 1 shows that this arrangement is not possible (the range of *Tolypaspis* is not shown as it is not clearly defined). But the first major effort to divide the whole series of these much-disputed rocks was made by Wickham King (1925, 1934), whose results, however much it may seem necessary to modify them in the light of new knowledge, must always remain the basis for any work of this nature. As I have already pointed out (White, 1946: 208), the stages into which King divided his Downtonian and Dittonian strata are 'lithological in conception and the palaeontological names which have been applied to some of them are based on maximum occurrences of fossils that may be of relatively local significance'. In that paper the case of the '*Psammosteus*' Limestones was dealt with, and it would not be difficult for one reason or another to find fault with the naming of a number of these stages: for

[1] Read before Section K of the International Geological Congress in London, 1948.

example, *Ischnacanthus*, the name-fossil of stage I. 6, is recorded by King himself (1934: 530–1) from below the Ludlow Bone-bed to the Dittonian and is not uncommon in beds reputed to be in stage I. 8; while there is evidence that the sandstones and cornstones which yield rich harvests of *Cephalaspis* occur at very different levels. After all, lithology is the geological expression of the conditions prevailing at the time of deposition and, subject to the limitations of time and space, similar rocks are likely to yield similar fossils: and thus as small a zoological unit as possible, preferably a species, must be used for zonal work. Moreover, in such mixed and variable estuarine and sub-estuarine deposits laid down off a moving shore-line repetitions in lithology are inevitable, for the material is water-sorted into a series of wedge-shaped beds in which the same general succession may often be repeated (cf. Marr, 1929: 78–80, text-fig. 3). And even widely spread deposits, such as the '*Psammosteus*' Limestones (or 'Psammosteid' Limestones, as King called them later), are unlikely in these circumstances to be strictly synchronous. Nevertheless, King's stages provide a most valuable starting-point. His classification for the West Midlands is as follows:

'II. DITTONIAN. 750–800 ft.	
4. Marls and thin sandstones	200–250′
3. Marls, cornstones, and sandstones	150′
2. Red and green marls and thin sandstones and cornstones	370′
1. *Cephalaspis* sandstone-cornstone	20–30′
'I. DOWNTONIAN MARLS. 2100–2400 ft.	
10. Marls with purple or green sandstones	100–150′
9. Eurypterid sandstones in red and green marls	90–150′
8. Psammosteid Limestones (1 inch–20 feet) and calcareous sandstones, in green and red marls	70–150′
7. Calcareous light purple and green sandstones, and limy concretions in distinctive bright red and some green marls	180–300′
6. *Ischnacanthus* sandstones and cornstones in red and green marls	90′
5. Deep purple and green marls	400–560′
4. Holdgate coarse sandstone	15–30′
3. Deep purple marls and thin purple sandstones	315–370′
2. *Thyestes* (*Auchenaspis*) or Ledbury marls and sandstones	400′
1. Temeside group (Elles & Slater)	100–200′

'The Ludlow Bone Bed of the Upper Ludlow.'

Two points may be emphasized here: the Ludlow Bone-bed is excluded from the Downtonian, and the whole of the Downtonian and Dittonian series is placed in the Silurian System (King, 1934: 553).

THE SUCCESSION OF FAUNAS

Since the publication of King's paper a very great deal of collecting has been done, adding greatly to our knowledge of the vertebrate faunas, while, so far as possible, previous records have been carefully checked. The following account with the diagram (Fig. 1) summarizes our knowledge of the vertebrate palaeontology of these beds and of the classification which has been based on them as applied in particular to the Shropshire–Herefordshire area (cf. White & Toombs, 1948: 5).

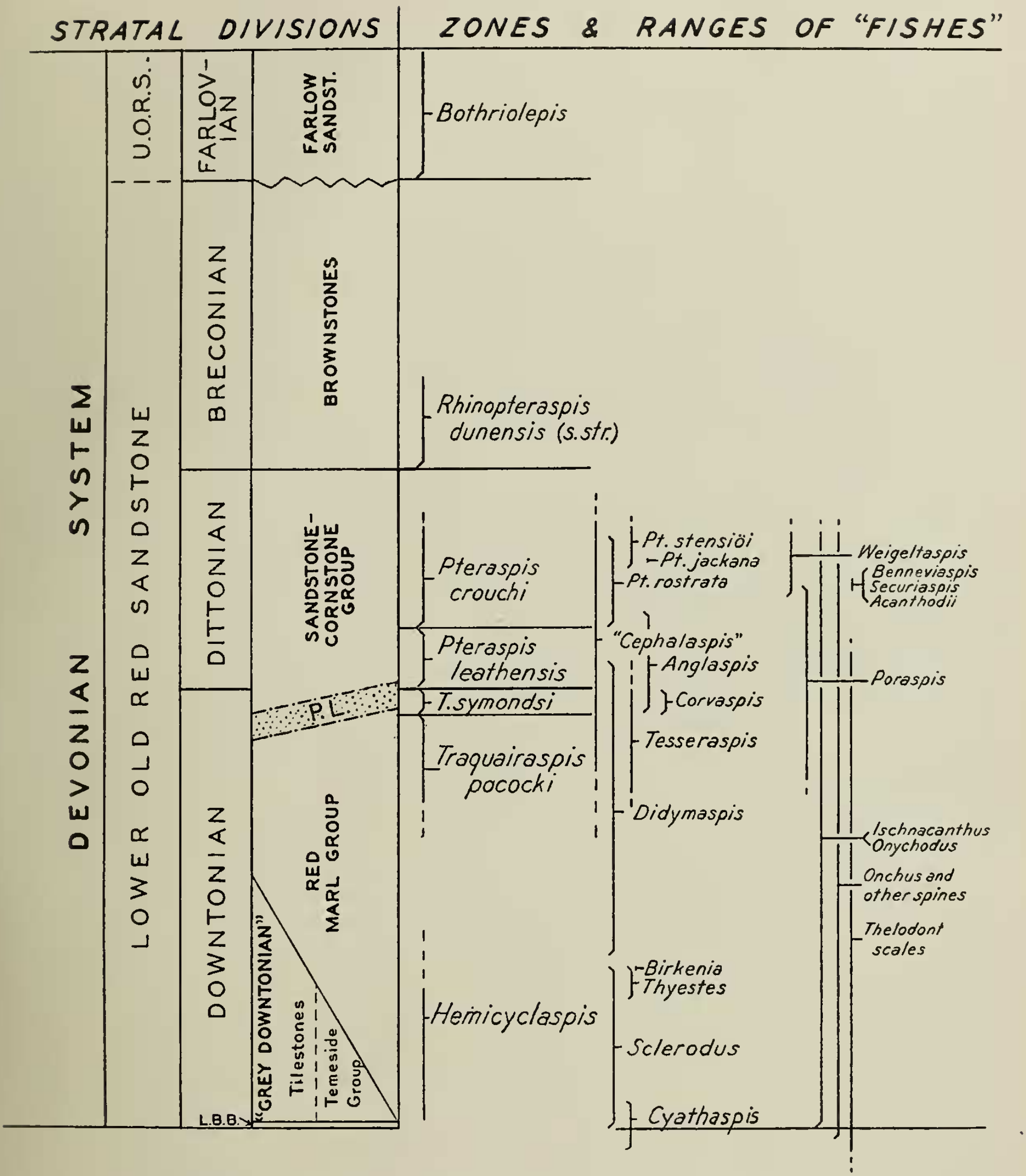


FIG. 1. Tentative classification of the Old Red Sandstone of the Welsh Borderland. The column is not to scale. [*L.B.B.*, Ludlow Bone-bed; *P.L.*, '*Psammosteus*' Limestones phase.]

The Downtonian may appropriately start with the Ludlow Bone-bed, which is only up to 6 in. in thickness. In my opinion there is far more reason from the palaeontological standpoint why this bed should be associated with the succeeding Downtonian strata rather than with the Ludlow Series. The survival in this bed of *Chonetes striatella* and of five other Ludlow species (four brachiopods and a lamellibranch) unknown in the succeeding strata is more than offset by the disappearance of the remainder of the marine fauna. Moreover, although a single specimen of a Cyathaspid (*Archegonaspis*) has been found as early as the Dayia shales (Alexander, 1936: 110) and two specimens of *Cyathaspis* itself[1] with *Thelodus* scales and an *Onchus* spine have been recorded from the Upper Ludlow (Straw, 1927: 88–9), nevertheless this bed is the first horizon which is marked by a definite vertebrate fauna in this region: *Sclerodus pustuliferus* marks the advent of the Cephalaspids in the Anglo-Welsh basin, *Cyathaspis banksi* represents the heterostracans, Thelodont scales the Coelolepids, while ichthyodorulites such as *Onchus* indicate the existence of Acanthodians and perhaps other groups (cf. lists given by Elles & Slater, 1906: 219–20; Stamp, 1923: 396–7).

The Temeside Series measures up to some 170 ft. in thickness in the Ludlow district where it forms the so-called 'Grey Downtonian' (Pocock & Whitehead, 1935, 1948, p. 63; see Fig. 2, p. 62 *infra*). It is divided into two zones by Elles & Slater (1906), a lower zone of *Lingula minima* comprising the 'Downton-Castle or Yellow Sandstones', which have yielded *Cyathaspis banksi*, especially plentiful at Bradnor Hill, and an upper zone of *Lingula cornea*, consisting of the 'Temeside or *Eurypterus* Shales'. In the latter occurs the Cephalaspid *Hemicyclaspis*, earlier records of which I have been unable to substantiate. The exact position of the *Thyestes* beds in the zone of *Hemicyclaspis* relative to the Temeside Series is apparently obscured by faulting both at Ludlow and in the famous Ledbury section. In the Ludlow railway cutting, of which no clear or measured section appears to have been published, they seemed to Murchison (1857: 290) to be 'some of the highest beds of the Ludlow Rock' (i.e. Upper Ludlow and Grey Downtonian) almost immediately underlying red marls; in the Ledbury section the *Thyestes* beds are high in the red series, but how high depends on the interpretation of this famous section. Some authors, such as Piper (1898: 313; King MS.), considered that the beds were faulted against the Downton Sandstone, and that most of the Temeside group, lying wholly beneath the red beds (King, 1934: 527), had been cut out. But the evidence is not entirely clear and the succession at Ledbury may be complete (Symonds, 1872: 99), the red rocks being precociously developed and coeval with much of the more typical Grey Downtonian of Ludlow: or to put it another way, the Grey Downtonian is a local development of the Red Marl Group, and the level at which the rocks change colour varies with the district. That this is so seems to be supported by the early appearance of the red beds some 50 ft. above the Bone-beds at Brock Hill, Malvern, $4\frac{3}{4}$ miles to the north-east (Phillips, 1848: 97; Salter, 1858: 10–11).

Purplish marls predominate throughout the Red Marl Group and form typically rather featureless country in which exposures are extremely unsatisfactory and

[1] Through the courtesy of Dr. R. M. C. Eager I have been able to examine these specimens, of which one, and probably both, is referable to *C. banksi*.

fossils correspondingly rare. How far up the *Hemicyclaspis* zone extends is therefore uncertain. The genus is at 450 ft. above the Ludlow Bone-bed in south Staffordshire (King & Lewis, 1917: 94) and more doubtful specimens (P.25387–8) originally recorded as '*Cephalaspis lyellii*' (Marston, 1882: 24) are known from Oakly Park, 2 miles west-north-west of Ludlow, apparently much above the Grey Downtonian.

In the upper part of the Red Marl Group reddish and greenish sandstones become prominent and two zones, each characterized by a species of the Ostracoderm genus *Traquairaspis*,[1] may be distinguished. Although the base of the lower zone, that of *T.* [*Phialaspis*] *pococki*, is as yet undetermined, it is interesting to note that near Stonehaven, Kincardineshire, *T. campbelli* which seems closely related to *T. pococki* is associated with a *Hemicyclaspis* that on present evidence is scarcely to be distinguished from *H. murchisoni*. Above the '*pococki*' beds is a zone of *T. symondsi*, maybe up to 150 ft. in thickness. The interesting lithological feature of these upper beds of the Red Marl Group is a phase with characteristic limestones, which vary individually in thickness (1 to 20 ft.) and number. These so-called '*Psammosteus*' Limestones form a marked and valuable feature in the field, noted as long ago as 1870 by M'Cullough (p. 35), for although not necessarily extensive as individual beds, the phase persists over a very wide area from Corvedale to Pembrokeshire and, indeed, has been used by some stratigraphers to separate the Downtonian from the succeeding Dittonian Series (see Fig. 2, opp. p. 62); there is, however, evidence to show that this phase is to some extent diachronic and may occur at levels varying from the top of the *T. pococki* zone, throughout that of *T. symondsi*, and perhaps even into the lower part of the succeeding Dittonian zone of *Pteraspis leathensis*. Since the original distribution of these species was given (White, 1946: 209–14), a number of new records have been added (Hurtle Hill, near Heightington, Worcs.; Mary Moors, near Trimpley; Onen, 5 miles north of west of Monmouth, and several others), from all of which *T. symondsi* has been obtained.

The term '"*Psammosteus*" Limestone' is frequently used in the singular as if only one limestone was present—indeed, it may be, locally, but in general the phrase is misleading, since there may be more than the one.

The difficulty of the fossiliferous levels at Gardener's Bank and Reaside Farm (White, 1946: 209), which are parts of a single long exposure, has now been satisfactorily cleared up by Mr. Toombs, who has shown that the contradictory reports of the position of the fossiliferous layers is due to faulting—in fact the specimens of *T. pococki* lie entirely under the rubbly limestone band, which is some 20 or 30 ft. thick and extends right under the Reaside Farm exposure before fading out, the specimens of *T. symondsi* occurring 10–20 ft. above it, giving a very clear proof of the relationship of the two species.

The vertebrate fauna associated with *T. pococki* consists of *Didymaspis grindrodi* which occurs within a foot or two of *Hemicyclaspis* in south Staffordshire (King &

[1] The English specimens of this genus were originally referred to *Psammosteus* and later to a new genus *Phialaspis*. New material from Cowie, Stonehaven, has shown that the plates described as *Phialaspis pococki cowiensis* are the ventral disks of *Traquairaspis campbelli*: the generic name must therefore be changed again.

Lewis, 1917: 94), *Tesseraspis tessellata*, *Ischnacanthus*, *Onchus*, *Onychodus*, and *Tolypelepis*, and for the first time in these parts '*Cephalaspis*', i.e. Cephalaspids with cornua other than *Thyestes* or *Sclerodus*.

The '*symondsi*' fauna is similar, but *Corvaspis* has not been found outside this zone and *Anglaspis macculloughi* occurs for the first time. The last named and perhaps *Didymaspis grindrodi* are the only well-defined species that pass up into the zone above, but representatives of the genera *Cephalaspis*, *Onychodus*, and *Thelodus* occur in both zones. *Corvaspis* and *Tesseraspis* have not so far been found in the succeeding zone, but the great change in the vertebrate fauna is the complete replacement of *Traquairaspis* by its distant and more orthodox relative *Pteraspis*. It is, accordingly, here, if anywhere, that a break should be made on palaeontological grounds between the Downtonian and Dittonian.

The lowest DITTONIAN zone is that of *Pteraspis leathensis*, a small blunt-snouted form which has been found in a number of different localities, mostly in the West Midlands, but reaching as far as Brecon (see p. 69 *infra*). The associated vertebrate fauna is relatively large—King (1934: 534) records 'Acanthodian spines' and *Didymaspis grindrodi*, while elsewhere *Poraspis* sp., *Anglaspis ?macculloughi*, *Thelodus* scales (*T.* cf. *schmidti*), Cephalaspid cornua, *Onychodus* teeth, and fragments of an undescribed Ostracoderm or Arthrodire have been found. The beds are chiefly greenish and grey, sometimes purplish sandstones with marls.

The succeeding zone of *Pteraspis crouchi* is considerably thicker, but the top of the range of this species cannot yet be determined, for the sandstones and cornstones, so typical of the lower beds, give way to more marly beds in which there are fewer exposures, and as yet no significant fossils have been found in them. But the lower beds are the most fossiliferous of the whole of the Lower Old Red in this region. The occurrence of the fossils seems highly capricious and local, for the beds are certainly lenticular, soon passing into the more usual barren strata. The dominant fossil is *Pteraspis crouchi*, which is of almost universal occurrence, and then less regular is *P. rostrata*, a variable species which is replaced in one locality by *P. jackana* and towards the top of the zone by *P. stensiöi*. *Securiaspis* and *Benneviaspis* occur rather rarely, but *Cephalaspis* itself is represented by no fewer than sixty 'species', of which less than one-third occurs in more than one locality. Generally the Pteraspids are represented only by isolated plates, usually the dorsal or ventral disks, and the Cephalaspids by head-shields, but in a single small lenticle at Wayne Herbert several complete specimens of *P. rostrata* and of seven species of *Cephalaspis* have been found with Acanthodians, including large Brachyacanthids more than a foot long. A similarly restricted bed at Cwm Mill has also yielded many complete specimens belonging to eight different species of *Cephalaspis*. Other Ostracoderms in this zone are *Poraspis sericea* and *Weigeltaspis*.

In Brecknockshire Mr. W. N. Croft has found in the greenish sandstones of the SENNI BEDS the very long-snouted Coblentzian *Rhinopteraspis dunensis* (s.str.). In Pembrokeshire, at Swanlake Bay (White, 1938: 87), a shorter-snouted form now treated as a separate species, *R. leachi*, occurs in beds reputed to be of lower Dittonian age (Dixon, 1933: 219), but the complexity of the faulting there makes the determination of these beds on stratigraphical grounds somewhat doubtful and, moreover, some of the fossils had been misidentified; therefore in the absence of any other critical information I prefer to regard these beds as of later date.

On the other hand, the reference of the beds near Kidwelly with the primitive *Pteraspis dixoni* (White, 1938: 100) to the Senni Beds on lithological grounds (Dixon, 1904: 37–8; 1939: 229) does suggest that there, at least, beds of Senni type occurred earlier than elsewhere in the Anglo-Welsh area, probably before late Dittonian times (cf. Pringle & George, 1948: 48).

THE ORIGIN OF THE FAUNAS

The interpretation of the conditions under which extinct animals lived and died, especially mobile aquatic animals such as arthropods and fishes, is not easy, but there are certain broad principles by which one may attempt to do so, and by which, briefly argued, I have concluded that the Downtonian and Dittonian vertebrate faunas are in the main spasmodic introductions into the brackish tidal waters from the fresh waters of the mainland (White, 1946: 216), and nothing has since come to light to cause me to modify this view.

With Tertiary and to a less degree with the late Mesozoic fishes one can determine their habitat to some extent by modern analogy, but the farther one goes back the less reliable this becomes and other factors become paramount. With the extinct groups of the Devonian the matter is complicated by the varied conditions then existing; in such an area as the Anglo-Welsh region the faunas may well have been of local brackish-water origin, either alone, or may be mixed with invaders from the truly marine areas or from fresh waters. Gunter (1947) has pointed out that in the modern fauna marine animals, particularly the less specialized forms, are very much more tolerant of lowered salinity than freshwater forms are of increased salinity; the former are therefore more likely to be found in estuarine areas than the latter and, indeed, frequently appear in fresh waters. This, of course, applies to fishes when *alive*; his further deduction that the finding of a fossil fish in a freshwater deposit does not preclude its marine origin, but that its occurrence in a marine deposit makes its marine origin certain must be questioned, for dead and dying fish usually float and in rivers would be swept into the estuaries, so that, in fact, the remains of freshwater fishes are the more likely to occur in estuarine beds. If Gunter's theory held for the Old Red forms, then the marine fauna would be difficult to distinguish from local estuarine species, except possibly by its wider distribution. But whether marine or estuarine, the normal inhabitants of an area would tend to be distributed throughout the rocks rather than to occur as isolated local concentrations, and, apart from local sorting due to winnowing, all parts of the animals would be present even though widely scattered—whether as fragments as in the London Clay or as whole animals as at Monte Bolca depends largely on the circumstances of their death and the rate of deposition. A local fauna destroyed catastrophically, as shown by extreme concentration, would still be detected by its relations to the fauna in the beds below, and possibly above. But the occurrence of the Lower Old Red faunas of the Anglo-Welsh area is peculiar, quite different from those just outlined. The fossils tend to be very localized both geographically and stratigraphically—great thicknesses of rocks seem to be normally barren, and then here and there in the series notable concentrations of Ostracoderms are found. Even where a species occurs throughout a thickness of strata, as do the zone fossils, they tend to occur at definite horizons and with varying associates, e.g. the *Thyestes* accompanying *Hemicyclaspis murchisoni* at Ludlow is *T. salteri*, at Ledbury it is *T. egertoni*, while extreme cases of individuality with very limited lateral distribution are to be found in the fossils of the Dittonian zone of the *Pteraspis crouchi*.[1] The widespread distribution of *Traquairaspis* in the '*Psammosteus*' Limestone phase suggests, like the occurrence of the limestones themselves, conditions of an exceptional kind.

In general these occurrences have the decided appearance of being interpolations derived from a distant source, which is further suggested by the degree, often intense, of water-sorting of the fossils themselves—and, indeed, in the case of the Dittonian deposits by the very different types of sediment in which they are found. These faunules readily call to mind the varied local faunas of complex river-systems, such as are found in South America and Africa to-day, the various branches of which have their own peculiar species of widespread genera and families (e.g. *Barbus*, Cichlids, and Cat-fishes) and all emptying their contents from time to time, by reason of periodic flooding and similar local accidents, into a common basin.

THE SILURIAN–OLD RED BOUNDARY

The vexed question of the Silurian–Old Red boundary has occupied the attention of authors ever since Murchison (1833: 475) first proposed his divisions of the upper part of the 'Grauwacke'. Whether it is really justifiable to endeavour to fix a limit on logical grounds at a single horizon between systems involving thousands of feet of strata may be questioned as straining too far the evidence provided by natural phenomena (cf. Leriche, 1922: 166): after all, the division of the stratigraphical column into systems is entirely a human concept based in detail, at any rate, on local accidents—often only the accident of the particular area where the strata were first studied. Murchison was clearly aware of the difficulties arising from attempting too great precision, and his writings on this subject throughout contain ambiguities and not a few apparent contradictions.

There are several accounts of the history of the Silurian–Old Red boundary question, but some are clearly erroneous and none seems complete; moreover, although one would not necessarily choose the historical division between two systems for modern usage, it is desirable to do so if possible, so that the matter is worth further consideration. In the present instance there has been no little disagreement as to the interpretation of the original author's intentions and the matter is discussed here in some detail.

In his first brief account of the Old Red Sandstone and underlying strata of the Anglo-Welsh basin Murchison (1833) was obviously dealing in very general terms with rocks over a wide area—he remarks (p. 474) on the 'gradual passage from the old red into the grauwacke' but 'however, insists that there are no two formations

[1] As in four quarries in south-west Herefordshire: Wayne Herbert quarry yields *P. rostrata* with 8 out of 12 Cephalaspids peculiar to it: Castle Mattock *P. crouchi*, *P. jackana*, and *P. stensiöi* with 12 out of 16 Cephalaspids peculiar: Pool Quarry *P. crouchi* and *P. rostrata* with 8 out of 15 Cephalaspids peculiar: Wern Genni *P. crouchi* and *P. stensiöi* with 3 Cephalaspids out of 7 peculiar to it. These quarries lie approximately and respectively at 220, 240, 350, and 650 ft. above the '*Psammosteus*' Limestones.

of the English series which can be better separated from each other for purposes of geological illustration, than the old red sandstone and the uppermost grauwacke; the former being as poor as the latter is rich in organic remains, whilst the colours and mineral characters of the two formations are also very distinct'. Further we read (p. 475) that the Upper Ludlow Rock (the top division of the rocks then generally known as 'grauwacke', underlying 'the base of the old red sandstone') 'is as eminently characterized by the presence of organic remains as the old red sandstone is by their deficiency. Amid a profusion of fossils, the upper beds are characterized throughout the whole range of the formation by two species of Strophomena or Leptæna, an Orbicula, a plicated Terebratula, &c., all of undescribed species'. If one glances at the list of fossils in Elles & Slater's paper (1906: 219–20), it seems clear enough where the 'profusion of fossils', including the brachiopods, stops in the type-area of the Ludlow Series—at the Ludlow Bone-bed: but whether Murchison intended such a definite line of demarcation, or for that matter even knew at this time of the existence of the Ludlow Bone-bed, is most improbable—it was not noted by him until 1839 (p. 198), when it was described as 'the central part of this stratum', i.e. the Upper Ludlow Rock (cf. Murchison, 1854: 137).

Murchison's next account (1834*a*, *b*) established the 'Tilestones' as the third and lowest group of the Old Red Sandstone, and where they contain fossils, as in Carmarthenshire and Shropshire they are said to constitute 'the beds of passage into the "*Ludlow Rock*", or highest member of the grauwacke series'. The chart accompanying the paper does not make the line of division any clearer by either the list of fossils or the schedule of localities, but the description of the Tilestones as 'Flaggy, highly micaceous, hard, red and green sandstone' seems to exclude such rocks as the 'Downton-castle building stone', as he later described it (1839: 198), and thus puts the boundary at any rate well above the Ludlow Bone-bed. Certainly, I can see no evidence for the latter part of Dorlodot's (1912: M300) statement that in 1834 the 'Tilestones' division 'Comprend, à sa base, les pierres de construction exploitées près du *Dow*(*n*)*ton Castle*'.

In 1835 Murchison first introduced the term 'Silurian System' and contrary to what Stamp (1923: 279) said, made no attempt to define the limits of the system at all, let alone fixing 'the lower limit of the Old Red Sandstone below the Downton Castle Sandstone, i.e. at the horizon of the Ludlow Bone-bed'. It was not until four years later, in *The Silurian System* (1839: 198), that the 'Downton-castle building stone', was named and both it and the Ludlow Bone-bed described; and then, as Jones (1929: 113) has pointed out, Murchison clearly puts the upper limit of his Silurian System at the top of the Downton Sandstone, for he refers (p. 181) to a 'freestone, of which Downton Castle is built, which will presently be described as constituting the upper stratum of the Silurian System'. However, after placing the 'Tilestones' unequivocally in the Old Red Sandstone, the strata between the Old Red Sandstone and the 'true upper Ludlow rock', as the Downton Castle building stone is called (p. 198), are at one and the same time described as 'beds of passage, which cannot be arbitrarily referred either to the Old Red or Silurian Systems', and placed firmly in the 'Upper Ludlow Rock' of the 'Upper Silurian Rocks' (p. 197)! Be that as it may, it seems to me that if any horizon has a right to be considered as the historical dividing line between the two systems, it is that first indicated by Murchison, the top of the 'Downton-castle building stone' as originally defined—that is, the top of bed *Ec* of Elles & Slater (1906: 198) and not the top of their 'Downton Castle or Yellow Sandstones', which comprise very much more than Murchison's 'building stone', being 30–40 ft. thick against the latter's 12–14 ft.

Later, of course, Murchison (1845; 485) transferred the Tilestones to the Silurian System on palaeontological grounds under, as Dorlodot (1912: M302) and Straw (1930: 95) have suggested, the misguided influence of faunal lists in which fossils from older rocks are included under the heading of 'Tilestones'. Murchison later admitted (1859: 149) that the fossils were obtained from 'Clun Forest and some parts of S. Wales, where the bone-bed has not yet been seen'—that is, from areas where the typical Ludlow sequence is not developed and where stratal boundaries are least clearly marked.

It is evident that Murchison never used the Ludlow Bone-bed as a boundary between stratal divisions, either major or minor, and Dorlodot's assertion (1912: M303, M366) that Murchison in 1842 (p. 648) considered the Ludlow Bone-bed to mark the top of the Silurian System is based on the misunderstanding of a piece of rhetoric removed from its context. Probably its first use as a boundary between the two systems may be attributed to Page (1859: 93).

After Murchison's work the next important development was the establishment by Lapworth (1879–80) of the Downtonian, composed of the Downton Sandstone (*s.s.*), Bone Beds (presumably Murchison's 'Fish Beds'), and the Upper Ludlow (erroneously printed in the table as 'Lower Ludlow'). It is therefore the exact equivalent of Murchison's 'true Upper Ludlow rock' (1839: 198–201). This term 'Downtonian' soon seems to have been abandoned by Lapworth (1888: 172), but it was later adopted by Peach & Horne (1899: 568) for beds supposed to correspond to Geikie's (1893: 753) top division of his Ludlow Group (consisting of 'Tilestones, Downton Castle Stone and Ledbury Shales') in the Lanarkshire and Ayrshire succession, comprising some 2,800 ft. of strata. This meant that in the Anglo-Welsh area of Lapworth's original 'Downtonian' only the 14 ft. of the original 'Downton-castle building stone' and a few feet of the 'Bone Beds' was left, the Tilestones and Passage beds being added above and the Upper Ludlow removed from below (Fig. 2).

Elles & Slater (1906) used the Ludlow Bone-bed as the upper boundary of their Upper Ludlow Group, thus dividing it from their 'Temeside Group', which for them formed the top of the Silurian System; but the real stratigraphical significance of this bed seems first to have been realized on the other side of the Channel, first by Dorlodot (1912) and then by Barrois, Pruvost, & Dubois (1918: 710; 1922: 225), who made it the base of the whole Devonian System—a suggestion which was readily accepted and elaborated by Stamp (1920; 1923).

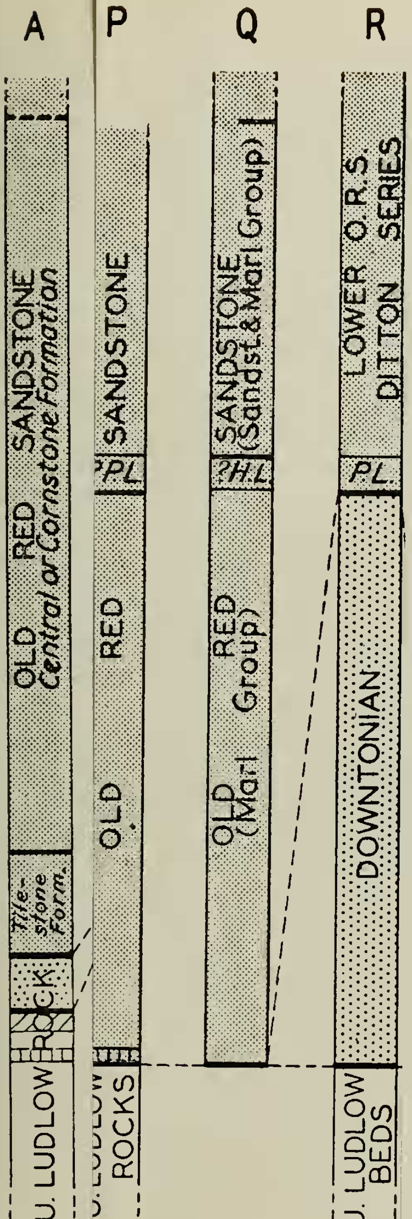
It is all the more unfortunate that these distinguished French authors have misunderstood Murchison's original statements regarding the boundary, and have in consequence put forward as further support for their otherwise admirable arguments historical evidence that is certainly erroneous. It is just not true, as Barrois, Pruvost, & Dubois have stated (1922: 214), that the upper limit of the Silurian System 'a été fixée d'abord, en 1838, par cet auteur (Murchison 1839), entre l'Upper Ludlow Rock et les Tilestones (grès de Downton) . . .' and then 'au Ludlow bone bed (sommet de l'Upper Ludlow Rock)'. One need only comment that in *The Silurian System* (*a*) the Downton Castle building stone is clearly placed in the Upper Ludlow Rock and not in the Tilestones (p. 198); (*b*) the upper limit of the Silurian System is placed at the top of the 'building stone' and not at its bottom (p. 181); and (*c*), as noted above, the Ludlow Bone-bed (a name which, incidentally, Murchison does not seem to have used until 1854, caption p. 143) is described as 'the central part of this stratum', i.e. of the Upper Ludlow Rock (p. 198), and not the top, and he seems never to have altered his opinion (1872: 133). As Jones (1929: 115) has pointed out, Geikie (1882: 682; 1903: 961) appears to have been the first to have misinterpreted Murchison who, he says, originally called the Downton Sandstone and 'the whole of these flaggy upper parts of the Ludlow group' Tilestones. What Murchison did do in *Siluria* (1854: 139) was to include his 'Downton Castle building stones' with the Tilestones in his 'band of transition', which is quite another matter, and we may note that by this time the Tilestones themselves had been removed to the Silurian System. Much of the difficulty may be traced to the varied use by Murchison of such terms as 'beds of passage', 'transition beds', and 'tilestones', e.g. in 1834: 12 we read 'these fossiliferous tilestones constitute the beds of passage into the "*Ludlow Rock*" ', whereas in 1839: 197 'tilestones' are in the Old Red Sandstone, but the 'beds of passage' are something lower, 'which cannot be arbitrarily referred either to the Old Red or Silurian Systems'.

In the meantime King & Lewis (1917) had initiated a most important innovation in respect of the Anglo-Welsh area of extending the Downtonian upwards to include some hundreds of feet of the overlying red beds, later (King, 1921*a*; 1925; 1934) to be increased to over 2,000 ft. of rocks, while a further 800 ft., all the strata previously referred to the Lower Old Red which were supposed to contain *Pteraspis crouchi* and *P. rostrata*, were placed in a new series, the Dittonian, and on the alleged grounds of faunal continuity both Downtonian and Dittonian were classed as Silurian.

Up to this point, the controversy regarding the boundary in the Welsh Border region had concerned only some 200 ft. of strata at the base, i.e. the beds between the Ludlow Bone-bed and the top of the Passage Beds; but Wickham King's ideas involved the almost complete annihilation of the Lower Old Red in the Anglo-Welsh region. So far King has not been largely supported in this revolutionary classification, but we may note Dahmer's (1948) provisional statement, based on the study of Mollusca, Ostracods, &c., that 'Alle Ablagerungen, die bisher unter der Bezeichnung "Gedinne" in der Literatur geführt und an die Basis des Devons gestellt wurden, haben Ludlow-Alter.' Allan (1935: 39) certainly fixed the Siluro-Devonian boundary 'to agree with the incoming in force of the faunas associated with the *cyclopterus-hystericus* type of *Spirifer*', that is, at the base of the Taunusian or Lower Siegenian in western Europe; but that author admits that this limit is artificial, since 'a complete succession of strata with marine faunas of the open-water type' exists in north-east America and 'where the facies is stable, therefore, there is no faunal break between the Silurian and the Devonian', and the value of this effort to establish a universal boundary is somewhat abated by his subsequent discovery (Allan, 1947: 451) that 'the similarity between the New Zealand fauna and that of Western Europe was to a large extent superficial and that many of the apparent similarities were based on comparison of homeomorphous groups'. Other authors have produced a remarkable number of varied classifications within recent years, as the accompanying Fig. 2 shows, and although in no case is the Dittonian included in the Silurian System, the position of the Downtonian still seems unsettled, some placing it in the Old Red, others in the Silurian, while still others leave the question open.

Obviously, such differences of opinion, and especially in the type-area, can only lead to further confusion both here and elsewhere, and therefore the arrangement here described, based on the more recent information regarding the vertebrate succession, is put forward only in the hope that it may help towards stability. In my opinion there is, as Wickham King suggests, a general faunal continuity throughout the Downtonian–Dittonian strata as illustrated by the first diagram, but I differ from him in considering that, so far as the Anglo-Welsh cuvette is concerned, the demands of both stratigraphy and palaeontology are best met by retaining the whole in the Lower Old Red Sandstone. The complaint of some writers that the break at the Ludlow Bone-bed does not provide a valid reason for placing the boundary there since the change in fauna is due to a change in facies (Leriche, 1922; Evans in Stamp, 1921: 8; in Stamp, 1923: 277; Allan, 1935: 46) does not seem to me to be wholly justified. The arguments in favour of using a marine succession as the standard in matters of stratigraphical definition were clearly stated many years ago by Blanford (1885: 706–11). In some ways the use of a marine succession is obviously preferable, particularly in that sea-faunas may move rapidly over wide areas, but the arguments are by no means all one-sided and some put forward seem rather two-edged—for instance, Elles's (1924: 87) contention 'that the faunas of the deeper-water areas where conditions are more uniform should furnish the standard for purposes of classification' is largely countered, quite unwittingly, by Allan's previously quoted remark (1935: 59) that 'where the facies is stable, therefore, there is no faunal break between the Silurian and the Devonian', and by his consequent selection of an artificial limit between them. Moreover, Miss Elles's further claim that under constant physical conditions any change in the character of the fauna 'is almost bound to be of real significance' is open to considerable doubt. If conditions were ideally uniform over a long period one might be able to detect in the fossil assemblages indications of varying rates of evolution in species or even larger groups of organisms (cf. Simpson, 1944: 48, &c.), but the general aspect of the fauna would be unlikely to show a discernible break at any one point; indeed, one would at once suspect that a faunal change in apparently continuous strata was due to a change in conditions, such as an increase or decrease in temperature or salinity, not reflected in the lithology. Allan's criticism (1935: 47) that 'it is inconceivable that an international classification can be based on the fish-faunas, which are, practically speaking, confined to a single facies in Western Europe', cannot be accepted, for to ignore the 'fish-faunas' in order to fix an admittedly artificial limit outside the original area based on another set of organisms seems unreasonable, and, as it turned out, not particularly fortunate (Allan, 1947: 451).

Leriche (1922: 164) has objected to Stamp's rather extravagant statement (1922: 91) that 'Le commencement du Dévonien correspond donc à l'aurore d'un âge de



d Dittonian strata in the Ang
ıes based on King 1934, but

l 1948: 63, 65.
d 1948, fig. 34.
7.

R. Dinhan
S. Pocock,
T. Trotter
U. Whiteh
V. Kellaw
W. Modifie

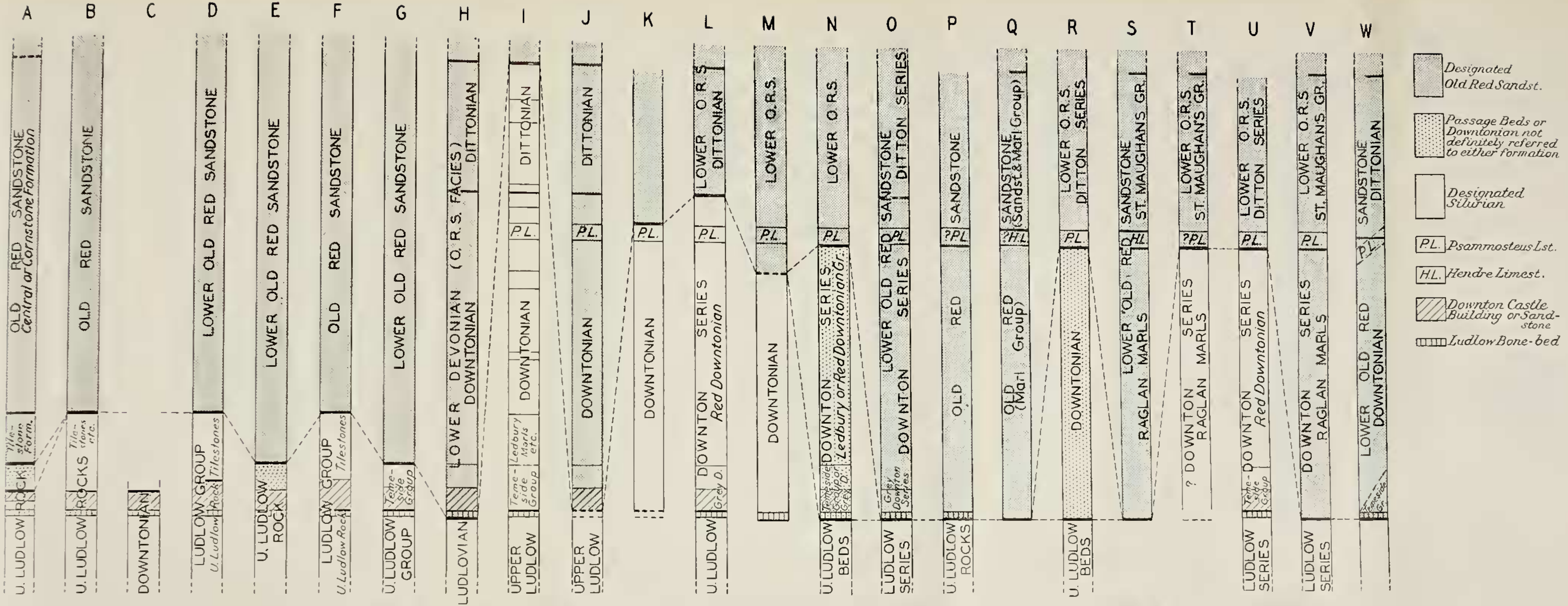


FIG. 2. Diagram illustrating variations in level of the Silurian–Old Red boundary and in the classification of the Downtonian and Dittonian strata in the Anglo-Welsh area published by field-workers since 1920 compared with the classifications of Murchison, Lapworth, Geikie, and Elles & Slater. (Comparative thicknesses based on King 1934, but thinner divisions much exaggerated.)

A. Murchison, 1839: 197–8.
B. Murchison, 1854: 138–9 (also 1872: 134–5).
C. Lapworth, 1879–80.
D. Geikie, 1882: 674, 681–2.
E. Lapworth, 1888: 173, 180.
F. Geikie, 1903: 953, 960–1.
G. Elles & Slater, 1906.
H. Stamp, 1920, 1923: 277.
I. King, 1921, 1925, 1934.
J. Richardson, 1935: 3.
K. Practice of the Geological Survey in Richardson, 1935: 3, footnote.
L. Pocock & Whitehead, 1935 and 1948: 63, 65.
M. Pocock & Whitehead, 1935 and 1948, fig. 34.
N. Edmunds & Oakley, 1935, 1947.
O. Pringle & George, 1937, 1948.
P. Rose, 1937: 58.
Q. Dunham, 1937–8.
R. Dinham, 1938: 34.
S. Pocock, 1940: 25.
T. Trotter, 1942: 9.
U. Whitehead & Pocock, 1947: 4–11.
V. Kellaway & Welch, 1948: 15.
W. Modified after White & Toombs, 1948.

vertébrés'—there were, of course, vertebrates long before those times—but if we consider the statement in a restricted geographical sense, it is true that in the Anglo-Welsh cuvette the remains of vertebrates appear as common and obvious fossils for the first time in the Ludlow Bone-bed.

Objections of some sort or another may, indeed, be raised to any division of strata based on palaeontological grounds—obviously, since life is continuous (or unless one believes in Special Creation), somewhere or other there are in strata coeval with the Silurian Upper Ludlow faunas immediately ancestral and perhaps hardly to be distinguished from, the Downtonian faunas, although they may never be brought to light. Faunas may vanish suddenly and finally (although such complete disappearances are probably rare in nature), but sudden appearances can only be local. Our choice of limits must therefore be to some extent arbitrary, and in disputed cases (which means in most cases) be subject to some agreed convention, of which the most obvious is a law of priority—that is to say, the division must be based on a standard succession which should be in the area first described and that the limit should approximate to that originally designated, having regard to the demands of practicability. In the case of the Silurian–Old Red boundary, the type-area is our Ludlow area and the originally defined boundary was the top of the 'Downton Castle building stone' of Murchison (1839: 198—bed *Ec* of Elles & Slater, 1906). In this instance the demands of practicability do require some slight adjustment, for this is not a level of any marked faunal change nor is it lithologically easily recognizable very far away from the immediate neighbourhood of Ludlow, so that one may consider, as other authors for a variety of reasons have already done, the claims of the Ludlow Bone-bed, only a matter of 15 ft. below in the typical Downton Castle area (Elles & Slater, 1906: 213, fig. 6). It is in this conspicuous and widely spread stratum that the incoming of the vertebrate faunas in the type area is most marked and corresponding changes have been noted in respect of the invertebrates and in the lithology at comparable levels in less typical areas of the cuvette (e.g. Straw, 1930: 95, 100; Earp, 1938: 150). Farther afield, satisfactorily close correlation between the type section and the more mixed successions should be possible when the faunas have been reconsidered in detail and through them with the more completely marine areas. As matters now stand the marine faunas are not well enough known (cf. Shirley, 1938; Dahmer, 1948) for their claims to be pressed against those of the continental faunas with their historical background in determining the uppermost limit of the Silurian System: indeed, there is likelihood of confusion were this done. It is essential that the boundary be fixed now and, in my opinion, the Ludlow Bone-bed provides by far the most satisfactory datum line from which to mark the boundary in other areas. This line has already been strongly advocated on the Continent, as we have previously noted.

In the mixed succession around Liévin, in north France, attempts have been made to correlate the beds with the Shropshire succession, but that the sections there reach so far down as the level of the base of our Downtonian is not now considered likely (Shirley, 1938). Barrois, Pruvost, & Dubois (1922: 180–4, &c.) believed that change from Silurian to Marine Devonian faunas took place a little before the onset of Old Red conditions, which first show themselves at the boundary between the

'Schistes de Méricourt' and the 'Psammites de Liévin', where alternations of marine and continental deposits are present.

The Psammites are interesting in that they have yielded a small *Poraspis*, *P. barroisi* and, more important, a small blunt-snouted *Pteraspis*, *P. gosseleti* (see Leriche, 1906), which is exceedingly close to *P. leathensis*, and I have no hesitation in suggesting the correlation of the 'Psammites' with the *leathensis* beds of our area.

This implies that the '*leathensis*' beds are of upper Lower Gedinnian age (Barrois, Pruvost, & Dubois, 1922: pl. vii) and that therefore the whole of the Downtonian, over 2,000 ft., must be equivalent to the marine 'Schistes de Méricourt', which are only up to 120 ft. thick; but Shirley (1938: 358) after reconsidering the marine faunas there suggests that the whole of the succession preserved, some 300–400 ft. of rocks, is probably post-Ludlow in age, the top of the Silurian being absent.

Thereafter, in France and Belgium (see Asselberghs, 1946) as over here[1] there follow beds with *Pteraspis crouchi* and *rostrata*, to be correlated with the Upper Gedinnian, and finally there are the Siegenian and Emsian beds with *R. dunensis*. Thus in general the successions on the Continent and in the Anglo-Welsh area show considerable resemblance to one another.

Säve-Söderbergh (1941) made a brief but comprehensive survey of the Downtonian-Dittonian rocks elsewhere and with his conclusions I find little to disagree—he does, I think, over-emphasize the importance of the faunal break between the two series at King's level, i.e. between the *leathensis* and *crouchi* beds—the more important break is certainly lower down, below the *leathensis* zone. He concludes that the Norwegian *Hemicyclaspis* fauna is early Downtonian, and correlates the Oesel main fish-bed with the Lower Ludlow—this, we may note again, contains a Cephalaspid referred to the genus *Thyestes*, and another identified as *Cephalaspis* itself.

The Spitsbergen faunas were also dealt with by Føyn & Heintz (1943: 42), who consider that the lower part of the Red Bay Series, the Fraenkelryggen Division, is of upper Downtonian age (i.e. lower Dittonian according to our classification), since it contains, besides numerous small forms of *Poraspis* and *Cephalaspis*, species of *Anglaspis* and a blunt-snouted *Pteraspis*, *P. primaeva*, possibly related to *P. leathensis* and at its base *Phialaspis* (*Traquairaspis*) and *Corvaspis*; while the succeeding Ben Nevis Division, with numerous Cephalaspids including *Benneviaspis*, is regarded as Dittonian in age. Säve-Söderbergh suggested that the Downtonian–Dittonian boundary (of King) may be some way down the Fraenkelryggen Division, and although our knowledge of neither the English nor the Spitsbergen faunas is yet sufficiently complete to justify more than broad generalizations, our present information regarding the Anglo-Welsh faunas suggests that only the base of the Fraenkelryggen Division should be considered to be Downtonian.

In conclusion, I would like to express my warmest thanks to those who have given me, as usual, every help in compiling these notes—Mr. Wickham King, ever generous

[1] The significance of the '*dewalquei*' fauna is uncertain, as the identity of that species, which has been referred to *R. dunensis*, is not clear. The association of *R. dunensis* with *P. rostrata* in the Grès de Vimy, based on specimens referred to *P. dewalquei*, is disputed (Asselberghs, 1943: B38 footnote), while the occurrence of *R. dunensis* in the 'carrière de l'Albaule' in beds supposedly equivalent to '*crouchi*' beds (Asselberghs, 1943) is not proven. Professor Asselberghs informs me that nowhere have *R. dunensis* and *P. crouchi* or *P. rostrata* been found directly associated.

with information and advice; Dr. R. W. Pocock, Professor L. J. Wills, and Mr. H. A. Toombs, without whose help in the field and laboratory much of this could not have been written; and Mr. F. M. Wonnacott, who prepared the bibliography.

BIBLIOGRAPHY

ALEXANDER, F. E. S. 1936. The Aymestry Limestone of the Main Outcrop. *Quart. J. Geol. Soc. Lond.* **92**: 103–115, pl. 8.

ALLAN, R. S. 1935. The Fauna of the Reefton Beds, (Devonian) New Zealand. *Palaeont. Bull. N.Z.* **14**: 1–72, pls. 1–5.

—— 1947. A revision of the Brachiopoda of the Lower Devonian Strata of Reefton, New Zealand. *J. Paleont., Menasha,* **21**: 436–52, pls. 61–63.

ASSELBERGHS, E. 1943. Sur l'extension verticale de *Pt. dunensis* en Ardenne. *Ann. Soc. géol. Belg.* **66**: 33–39.

—— 1946. L'Éodévonien de l'Ardenne et des régions voisines. *Mém. Inst. géol. Univ. Louvain,* **14**.

BARROIS, C., PRUVOST, P., & DUBOIS, C. 1918. Sur les couches de passage du Silurien au Dévonien dans le bassin houiller du Pas-de-Calais. *C.R. Acad. Sci. Paris,* **167**: 705–710.

—— 1922. Considérations générales sur les couches siluro-dévoniennes de l'Artois. *Mém. Soc. géol. Nord,* **6**: 165–225.

BLANFORD, W. T. 1885. Presidential Address to Section C (Geology). *Rep. Brit. Ass. Adv. Sci.* **1884**: 691–711.

DAHMER, G. 1948. *In* Solle, G. *Devon.* FIAT Review of German Science 1939–1946. Geology and Palaeontology: 116. Off. Mil. Gov. Germany, Wiesbaden.

DINHAM, C. H. 1938. *Summ. Progress Geol. Surv. Lond.* **1937**: 34.

DIXON, E. E. L. 1904. *Summ. Progress Geol. Surv. Lond.* **1903**: 37–38.

—— 1933. Some recent stratigraphical work in its bearing on South Pembrokeshire problems. *Proc. Geol. Ass. Lond.* **44**: 217–225.

—— 1939. Discussion on A. Heard's paper. *Quart. J. Geol. Soc. Lond.* **95**: 228–229.

DORLODOT, H. DE. 1912. Le système Dévonien et sa limite inférieure. *Ann. Soc. géol. Belg.* **39**: M291–371.

DUNHAM, K. C. 1937–8. *Summ. Progress Geol. Surv. Lond.* **1936**: 58; **1937**: 28–29.

EARP, J. R. 1938. The Higher Silurian Rocks of the Kerry District, Montgomeryshire. *Quart. J. Geol. Soc. Lond.* **94**: 125–160, pls. 12, 13.

EDMUNDS, F. H., & OAKLEY, K. P. 1936, 1947. *British Regional Geology. The Central England District,* 1936: 23–29; 1947, 2nd ed.: 21–27. Dep. Sci. Industr. Res., Geol. Surv. Mus.

ELLES, G. L. 1924. Evolutional Palaeontology in relation to the Lower Palaeozoic Rocks. Presidential Address to Section C (Geology). *Rep. Brit. Ass. Adv. Sci.* **1923**: 83–107.

—— & SLATER, I. L. 1906. The Highest Silurian Rocks of the Ludlow District. *Quart. J. Geol. Soc. Lond.* **62**: 195–222.

FØYN, S., & HEINTZ, A. 1943. The Downtonian and Devonian Vertebrates of Spitsbergen, VIII. The English–Norwegian–Swedish Expedition 1939. Geological Results. *Skr. Svalb. Ishaver.* **85**.

GEIKIE, A. 1882, 1893, 1903. *Text-book of Geology.* 1st ed., 971 pp.; 1893, 3rd ed., 1147 pp.; 1903, 4th ed., 1472 pp. London.

GUNTER, G. 1947. Paleoecological import of certain relationships of marine animals to salinity. *J. Paleont., Menasha,* **21**: 77–79.

JONES, O. T. 1929. *In* Evans, J. W., & Stubblefield, C. J. *Handbook of the Geology of Great Britain*: 88–121. London.

KELLAWAY, G. A., & WELCH, F. B. A. 1948. *British Regional Geology. Bristol and Gloucester District.* 2nd ed., 99 pp., 12 pls. Dep. Sci. Industr. Res., Geol. Surv. Mus.

KING, W. W. 1921*a*. The Geology of Trimpley. *Trans. Worcs. Nat. Club,* **7**: 319–322.